



# Long-term trend and correlation between vegetation greenness and climate variables in Asia based on satellite data

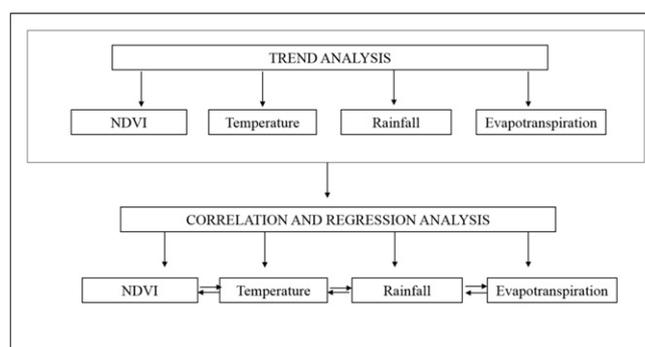
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## HIGHLIGHTS

- Temperature is the main climatic variable affecting vegetation greenness.
- A downward trend in vegetation greenness was observed during summer (April to October).
- Temperature showed an upward trend across many areas of Asia during the study period.
- In winter, rainfall showed downward and upward trends in different parts of Asia.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Satellite data has been used to ascertain trends and correlations between climate change and vegetation greenness in Asia. Our study utilized 33-year (1982–2014) AVHRR-GIMMS (Advanced Very High Resolution Radiometer - Global Inventory Modelling and Mapping Studies) NDVI3g and CRU TS (Climatic Research Unit Time Series) climate variable (temperature, rainfall, and potential evapotranspiration) time series. First, we estimated the overall trends for vegetation greenness, climate variables and analyzed trends during summer (April to October), winter (November to March), and the entire year. Second, we carried out correlation and regression analyses to detect correlations between vegetation greenness and climate variables. Our study revealed an increasing trend (0.05 to 0.28) in temperature in northeastern India (bordering Bhutan), Southeast Bhutan, Yunnan Province of China, Northern Myanmar, Central Cambodia, northern Laos, southern Vietnam, eastern Iran, southern Afghanistan, and southern Pakistan. However, a decreasing trend (0.00 to –0.04) was noted for specific areas in southern Asia including Central Myanmar and northwestern Thailand and the Guangxi, Southern Gansu, and Shandong provinces of China. The results also indicated an increasing trend for evapotranspiration and air temperature accompanied by a decreasing trend for vegetation greenness and rainfall. The temperature was found to be the main driver of the changing vegetation greenness in Kazakhstan, northern Mongolia, Northeast and Central China, North Korea, South Korea, and northern Japan, showing an indirect relationship ( $R = 0.84–0.96$ ).

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## 1. Introduction

The Normalized Difference Vegetation Index (NDVI) is commonly used to determine the vegetation distribution and productivity (Evans

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et al., 2006; Xiao and Moody, 2004) and to monitor the green cover. Based on many global and regional studies, the NDVI can be used to demonstrate spatiotemporal vegetation characteristics (Piao et al., 2003; Zhang et al., 2009); it has been largely used to digitally correlate climatic and environmental factors such as land surface temperature, precipitation (Piao et al., 2006), and evapotranspiration (Di Bella et al., 2000). Because global climate change has become a main subject of discussion, correlations between NDVI and climatic factors have gained importance in ecological studies (Gao et al., 2012). Climate effects are expected to influence interannual changes in vegetation growth; correlations between NDVI and climate data have been studied on regional (Li and Kafatos, 2000) and global (Schultz and Halpert, 1995) levels.

Some analyses indicated a temporal lag between rainfall and the vegetation response; it has been suggested that the vegetation is more susceptible to rainfall that accumulated over a longer period compared with instant rainfall (Wang et al., 2003; Herrmann et al., 2005). Other studies implied that the susceptibility and temporal effect of vegetation on climate change depend on the area and land cover type (Richard and Pocard, 1998; Wang et al., 2003).

One of the biggest dryland is central Asia of global and the impact of climate change on the environment and humans is highly variable (Lioubimtseva and Henebry, 2009). Water is scarce in this area, which poses significant threats to both humans and ecosystems. The vegetation development during the growing season depends on the rainfall in many ecosystems of this region. It is expected that the seasonal distribution of rainfall patterns changes and extreme events become increasingly frequent due to climate change. The growing season lasts from approximately April or May until October in Central Asia; winter temperatures mostly limit the vegetation growth (Ursula et al., 2013).

Hijioka et al. (2014) found that warming trends have been indicated with decreasing numbers of cold days and nights and increasing numbers of warm days and nights since the 1950s in most parts of Asia. Attri and Tyagi (2010) reported while average increasing temperature trends on the order of 0.56 °C–0.68 °C were observed on the Indian subcontinent. Gautam et al. (2013); Bhutiyani (2016) said that warming trend was especially strong in mountainous areas in South and Central Asia, at the elevation area in the Western, Central, and Eastern Himalayas, and in the nearby Tibetan Plateau (Liu and Chen, 2000) and surrounding mountainous areas (Giese et al., 2007; Dagvadorj et al., 2009). At higher altitude, the temperature has increased at a rate of up to 1.2 °C per decade since ~1980 (Yang et al., 2011), with faster strong increases in temperature in the past two decades (Kattel and Yao, 2013).

Our study provides an analyses seasonal trends in NDVI and climate variables for finding correlations between the vegetation greenness and climate variables. Specifically, our study aimed to answer the following questions:

- i. What are the trends of vegetation greenness and monthly average daily maximum temperature (°C), rainfall (mm per month), and potential evapotranspiration (mm per day) during the growing season (April to October) and winter season (November to March) from 1982 to 2014 across of Asia?
- ii. What caused the observed trends and the correlations between vegetation greenness and climate variables such as temperature, rainfall, and potential evapotranspiration and vegetation growth in the study area, overall and during the growing season (April to October) of the last 33 years?

## 2. Materials and methods

### 2.1. Study area

Asia located in the northeastern hemisphere at 35°N–55°N and 46°E–85°E (Fig. 1). Central Asia has a land area of  $5.6 \times 10^6$  km<sup>2</sup> and includes most (80%–90%) of the world's cold and temperate deserts

(Mchenry, 1997). Central Asia comprises the following countries: Tajikistan, Kazakhstan, Kyrgyzstan, Uzbekistan, Turkmenistan, and Afghanistan. Dry land in Asia has a temperate continental arid climate there are hot in summer and very cold in winter. The mean temperature in July is 32 °C; the total rainfall during the growing season ranges from 0 to 500 mm. The regional climate transitions from semiarid in the north to arid in the south. Land cover types mostly comprise meadow and desert steppe; deserts have a wide transition zone including semi-deserts, shrublands, grasslands, and forests. Land degradation is one of the mainly important problems in central Asia.

Northeast Asia includes Mongolia, China, Japan, North Korea, and South Korea. Northeast Asia comprises mostly temperate deciduous and boreal forest areas of northern China, Korea, and northern Japan. It covered parts of the boreal, cool temperate, and typical temperate zones and polar areas and mountain belts. The climate of the region thus permits forest vegetation throughout the year, with primarily boreal, mixed forests and temperate deciduous. Both sub-boreal forests and those comprising admixtures of evergreen broad-leaved taxa from the further south can be found in the area. However, the main areas of the border the Pacific, they are buffered from the direct oceanic influence by marginal seas (Sea of Okhotsk, Sea of Japan, and East China Sea), a unique feature of East Asia. As a result, strong continental gradients occur throughout the area.

Southeast Asia divide of two different areas: the Indochina Peninsula and Insular Southeast Asia. The Indochina Peninsula includes Thailand, Vietnam, Cambodia, Laos, and Myanmar. This area has a humid subtropical climate with a dry winter season; much of the area receives a high amount of annual rainfall (Southeast Asia, 2009). Most of the Indochina Peninsula, there are with tropical forests including rainforests and monsoon forests (Southeast Asia, 2009).

Based on the National Intelligence Council (2009), South Asia comprises Afghanistan, India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan, and the Maldives. South Asia covers ~5.1 million km<sup>2</sup> and is characterized by high biological diversity and climatic variations. Generally, there are two long seasons: summer (April–June) and winter (October–February). The diversified relief produces annual rainfall varying from 100 mm in the desert regions to 11,000 mm in the northeastern hills. The mean annual temperature varies from 2 °C to 50 °C and defines the tropical, subtropical, temperate, and alpine zones.

### 2.2. Data

#### 2.2.1. Remote sensing vegetation data

The NDVI dataset is the newest version of the Global Inventory Modelling and Mapping Studies (GIMMS) NDVI3g. It is derived from the US National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) satellite record and is the long-term global monthly time series of the greenness index, more than twice long as those from newer sensors such as the US National Aeronautics and Space Administration's (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS, February 2000 until present). The NDVI3g data were collected over a 33-year period ranging from 1982 to 2014 with a spatial resolution of 8 km and calculated using the average monthly NDVI from January to December. Northern Hemisphere latitudes (30°N–90°N) were analyzed in this study.

#### 2.2.2. Climate observation data

Monthly average daily maximum temperature (°C), rainfall (mm per month), and potential evapotranspiration (mm per day) data were provided by the Climatic Research Unit Time Series (CRU TS). The current version of CRU TS3.2 released in 2012. The dataset has a resolution of  $0.5^\circ \times 0.5^\circ$  and is based on the analysis of over 4000 individual weather station records. Major of the input records have been homogenized; however, the dataset itself is not strictly homogeneous. We used monthly climate data of the same period as the NDVI time series (1982–2014), the average monthly temperature, rainfall, and evapotranspiration of the

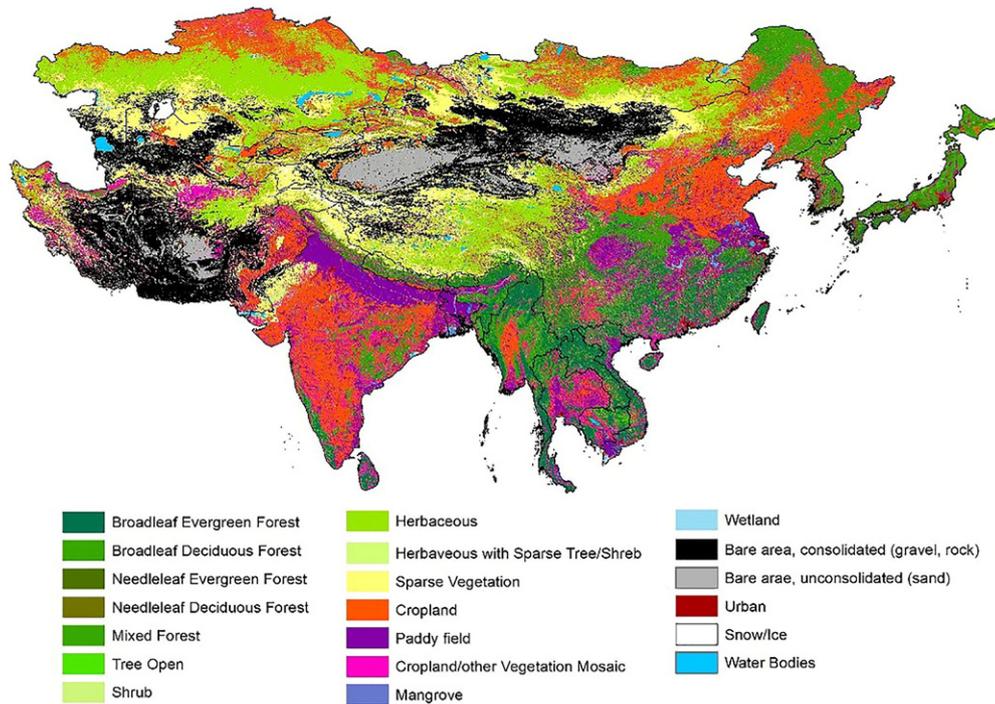


Fig. 1. Land cover map of the study area in Asia, 2013 (GLCNMO-version data).

whole season from January to December and totally 1536 data of 384 months. We changed cell size to 0.083 same with NDVI3g data (8 km) and column 1319, row 598 of all the climate data using Arc GIS.

### 2.3. Data analysis

#### 2.3.1. Temporal trend analysis

The monotonic trend (Mann–Kendall) option provides a nonlinear trend indicator that measures the degree to which a trend is consistently increasing or decreasing. It ranges from  $-1$  to  $+1$ . A value of  $+1$  demonstrates a trend that continuously increases and never decreases. The contrary is true when the value is  $-1$  and 0 value is demonstrated no consistent trend.

The trend of the time series data can be computed using a nonparametric technique that was introduced by Theil (1950) and developed by Sen (1968). The Theil–Sen (TS) slope estimator is the median of the slopes computed for values observed at all pairwise time steps for a total of  $n(n-1)/2$  slopes. This method has many advantages. The TS technique is robust against outliers and has the ability to reject anomalies without affecting the slope. The number of anomalies that this approach can reject without being affected (known as the breakdown bound) equals approximately 29% of the sample size (Neeti and Eastman, 2011).

#### 2.3.2. Statistical analysis

The linear association between the NDVI and climatic variables and vegetation growth was determined using single correlation ( $R$ ) and coefficient of determination ( $R^2$ ) of regression analyses. The relationship coefficient,  $R$ , is a measure of the strength of a linear relationship between two variables. The coefficient of determination,  $R^2$ , is the proportion of the variation of a response variable that is explained by a fitted statistical model;  $R^2$  is mostly demonstrated as a percentage. The relationship is computed from the strength of the linear correlation between NDVI and temperature, rainfall, and potential evapotranspiration by computing the per-pixel relationship coefficient ( $R^2$ ) from 33-years of overlay monthly observations (January 1982 to December 2014). And for more clear identifying the local differences, residual maps with dependent

variable of NDVI and independent variables of temperature, rainfall, and potential evapotranspiration.

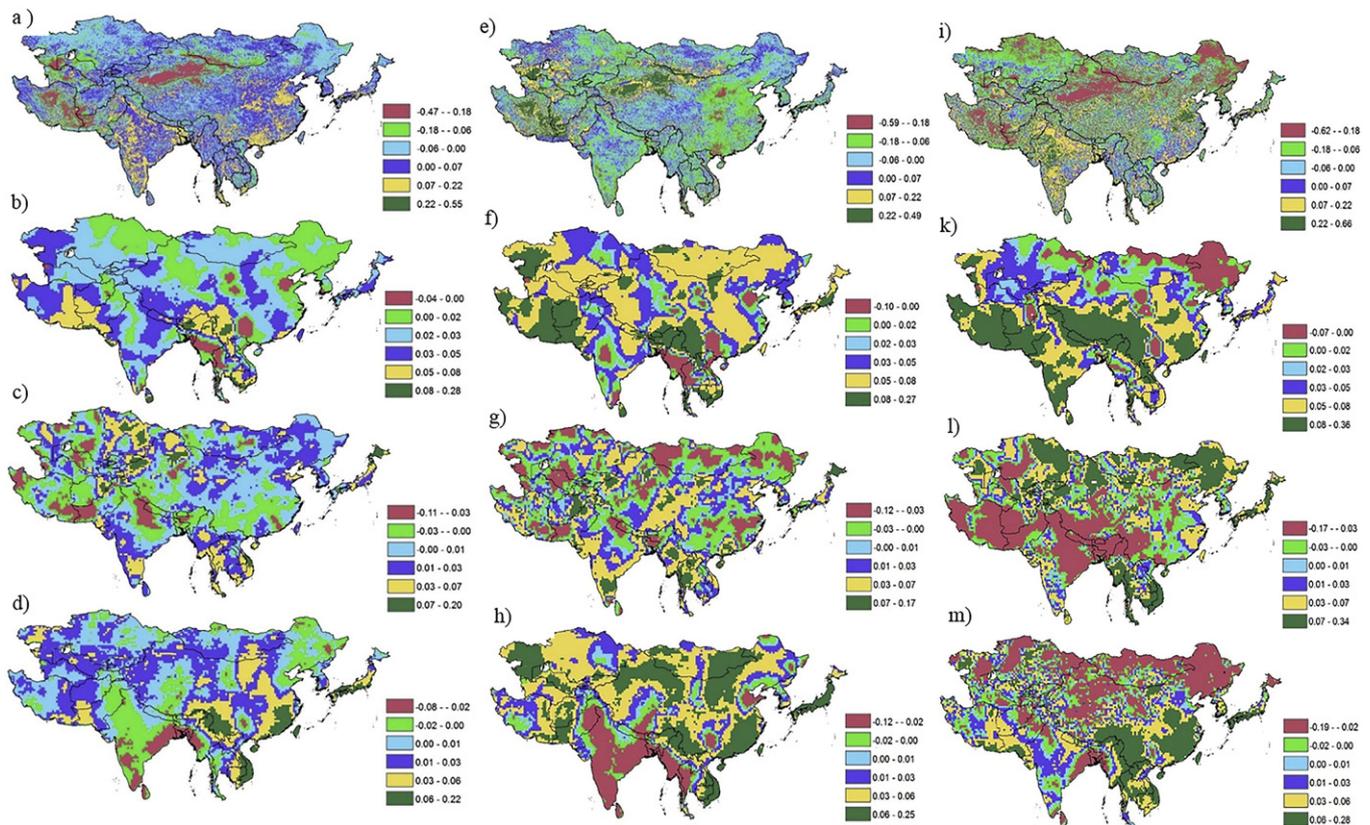
## 3. Results and discussion

### 3.1. Trend analysis for vegetation greenness and climate variables

Over the 33-year period, the vegetation greenness trend consistently decreased (range =  $-0.47$  to  $-0.08$ ) in eastern Iran, southwestern Afghanistan, southwestern Pakistan, Turkmenistan, Uzbekistan, southwestern Kazakhstan, northwestern China, and southern Mongolia, which is probably due to the fact that they are covered with arid land including sand dunes and the Gobi desert (Fig. 2). However, a smaller decrease (range =  $-0.08$  to  $0.00$ ) of the vegetation cover was observed in Central Asia, Afghanistan, Pakistan, northern India, Mongolia, eastern China, North China, North Korea, Sapporo of Japan, Nepal, Bhutan, Myanmar, Laos, Cambodia, and Vietnam. The brown and cyan colors indicate a negative change in vegetation or precipitation, whereas the yellow and green colors reflect positive changes. Blue indicates a normal change.

In most of the study area, the vegetation greenness has significantly decreased over the last 33 years. However, it is interesting to note that the analysis period covering January 1982–December 2014 is characterized by positive values and normal (range =  $0.00$  to  $0.07$ ) or slightly increasing (range =  $0.07$  to  $0.22$ ) vegetation greenness trends in India, southern China, Thailand, South Korea, and Japan (Fig. 2a).

The temperature has increased (range =  $0.02$  to  $0.28$ ) in many areas of Asia during these years. A decrease in temperature (range =  $-0.04$  to  $0.00$ ) was observed in central Myanmar, northwestern Thailand, and Guangxi and Shandong provinces of China. Mostly increasing trends were registered in areas of eastern India bordering Bhutan, southeast Bhutan, Yunnan of China, Iran, Afghanistan, and Pakistan. However, the most positive and most negative trends were observed on the Indochina Peninsula in Southeast Asia (Fig. 2b). The majority of rainfall in Iran, Afghanistan, Pakistan, northeast India, Uzbekistan, western Kazakhstan, southeastern China, and western-central Mongolia exhibits negative trends (range =  $-0.11$  to  $-0.03$ ) in recent years, while rainfall in eastern Kazakhstan, southern India, southern Myanmar,



**Fig. 2.** NDVI (a, e, i), temperature (b, f, k), rainfall (c, g, l), and potential evapotranspiration (d, h, m) trends based on Mann–Kendall tests by November to March (left), April to October (middle), and annually (right) of 1982–2014.

Thailand, Vietnam, South Korea, northeastern and central China, northeastern Mongolia, and northern Japan generally shows positive (range = 0.01 to 0.20) trends (Fig. 2c).

The potential evapotranspiration decreased ( $-0.08$  to  $0.00$ ) in India, Bangladesh, southern Myanmar, and northeastern China, indicating increasing water availability. The decrease in the potential evapotranspiration is related to the increase in precipitation and decrease in temperature (Fig. 2d).

Fig. 2e shows the trends during the summer season (April to October); a decreasing trend in vegetation greenness is observed in most of the study area. Interestingly, a positive vegetation value was recorded in arid and bare areas. Fig. 2b, f, k shows the increasing temperature in the study area. However, during winter, more increases were observed in southern and southeastern Asia, while decreases occurred in northeastern Asia. Negative rainfall difference values were distributed over most of the area during the growing season; however, positive values were obtained for the growing and winter seasons in south India, Myanmar, Thailand, Northern Japan, and northeast Kazakhstan. In the winter season, the rainfall decreased in southwestern China, northeastern India, Iran, Afghanistan, and Pakistan but increased in Central Asia, Northeast Asia, and Japan (Fig. 2i).

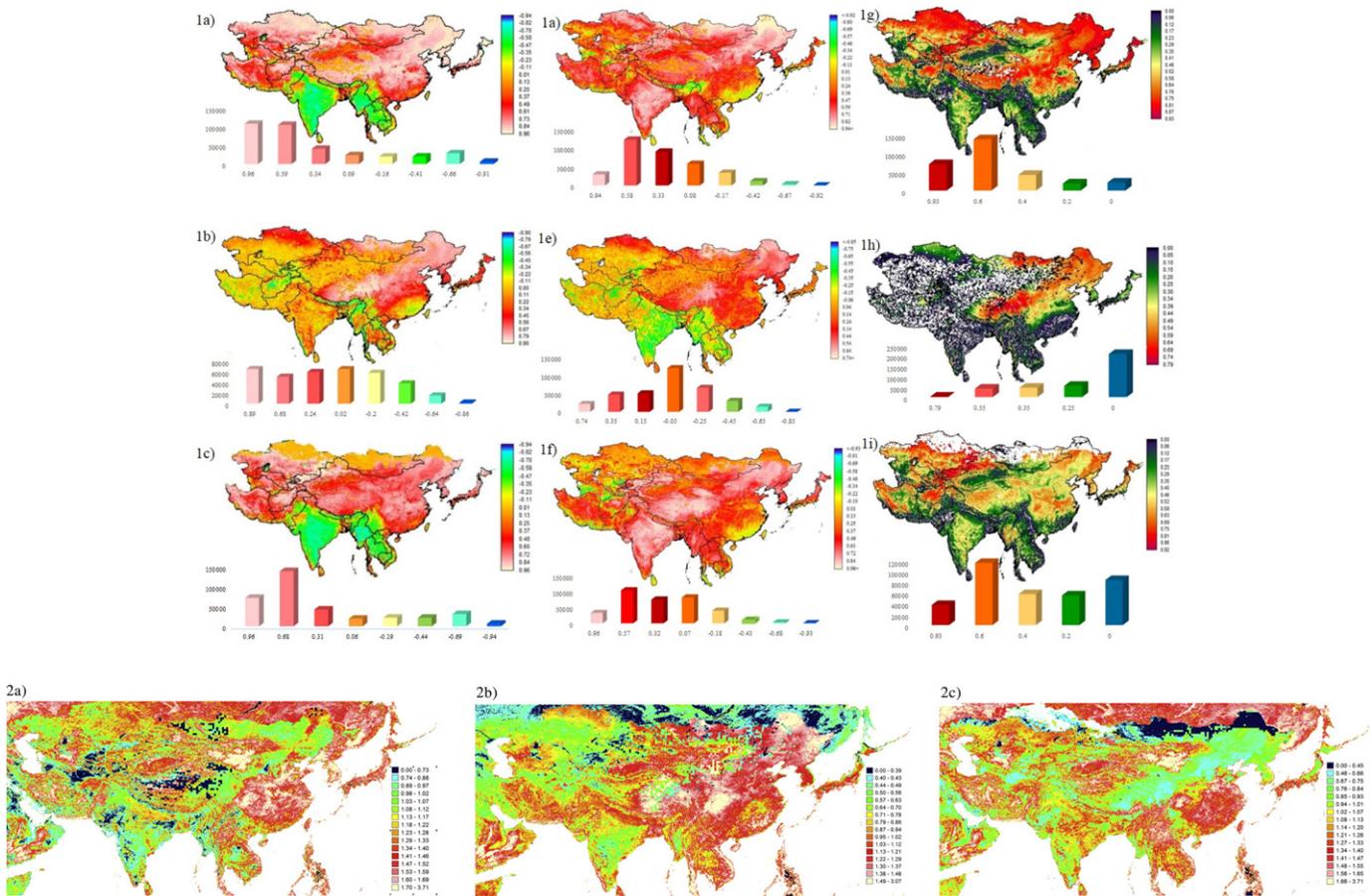
### 3.1.1. Correlations and linear regressions for NDVI and climate variables

Linear regressions and correlations were used to model the series of monthly NDVI as the dependent variable based on the independent variables of temperature, rainfall, and potential evapotranspiration. Per-pixel slope, intercept terms, and a spatially explicit coefficient of determination was computed for the modelled relationship using the Earth Trends Modeler of the TerrSet software package. The models were calculated using the 33-year series containing 396 months of each factor and 33 independent annual series. The model results for  $R$  and  $R^2$  are shown in Fig. 3.

Fig. 3.1a shows the correlation map for NDVI and temperature of for last 33 years. The red to white variations indicate statistically significant positive trends ( $R = 0.30$  to  $0.90$ ), while the yellow to green variations reflect statistically significant negative trends ( $R = -0.10$  to  $-0.90$ ). Most of the study area shows a significant correlation between NDVI and temperature ( $R = 0.30$  to  $0.90$ ) in the northern part of Asia during this period.

A belt of significant positive  $R$ -values characterizes the study area (Fig. 3.1b), indicating regions in which vegetation greenness and rainfall are positively correlated. The rainfall controls NDVI in China, northern Mongolia, northern Kazakhstan, Japan, and South and North Korea. The correlations between NDVI and changing rainfall were negative (yellow to green color) in Iran, Afghanistan, Pakistan, Turkmenistan, Uzbekistan, southern Kazakhstan, northwestern China, and southern Mongolia ( $R = -0.10$  to  $-0.70$ ). These areas are covered with sand dunes and deserts; hence, rainfall was not the main limiting factor for vegetation growth. The rainfall was sufficient for the types of vegetation growing in these arid and semiarid zones. However, India, Nepal, Bhutan, Myanmar, Laos, Vietnam, Cambodia, Taiwan, and southeastern China in tropical wet and humid subtropical zones also showed a negative correlation between NDVI and changing rainfall. In Fig. 3.1c, the NDVI - evapotranspiration correlation is similar to that for NDVI and temperature (Fig. 3.1a), with the highest positive values in the northern part of Kazakhstan, Mongolia, and northeastern China. In contrast, Fig. 3.1c shows the inverse result for the same area.

In addition, we analyzed the correlation of all variables during summer in the study area (middle column in Fig. 3.1d, e, f). The results for the summer season at many of the sites indicated positive correlations for vegetation greenness and temperature, while negative correlations were observed in Bhutan and along the border of India and Bhutan. The regression analysis (Fig. 3.1g, h, i) showed changes in vegetation greenness related to temperature (red color) for some areas of India and Myanmar (Fig. 3.1g). In Mongolia, Northeast and Central China,



**Fig. 3.** Frequency graph distribution and map of coefficient of determination ( $R^2$ ) for all seasons (left) and correlations ( $R$ ) for the growing season from April to October (middle) and for all months (right) for NDVI and temperature (1a, 1d, and 1g), NDVI and rainfall (1b, 1e, and 1h), NDVI and potential evapotranspiration (1c, 1f, and 1i). Residual maps with Dependent variable of NDVI and Independent variables of temperature (2a), rainfall (2b), and potential evapotranspiration (2c).

and North Korea, rainfall was the main climatic variable driving vegetation greenness changes (Fig. 3.1h). In addition, air temperature and evapotranspiration also affected the vegetation greenness.

The temperature in Bhutan, Nepal, Northern India, Bangladesh, and Northern Myanmar increased with decreasing rainfall. Decreased vegetation greenness was confirmed in central Asia, northeastern and western China, and southern Mongolia. Vegetation greenness continuously increased in some areas of western India, eastern India, and southern and eastern China. The vegetation and potential evapotranspiration are weakly correlated in the northern part of Kazakhstan, the northern part of Mongolia, and northeastern China, which is probably due to short summer seasons. The correlations between vegetation greenness and temperature were the strongest in Northeast China, Central China, northern Mongolia, northern Kazakhstan, North and South Korea, and northern Japan. The regression analysis suggested that the vegetation cover depends on two main climate factors (temperature, rainfall) in northern Mongolia, Northeast China, Central China, and North Korea. In the Fig. 3.2a, 2b, 2c, we showed residual distribution of with dependent variable of NDVI and in dependent variables of temperature, rainfall and evapotranspiration. The higher residual was observed in the eastern Asia of Fig. 3.2a, and in the almost part was observed higher residual in the past 33 years of Fig. 3.2b. This local difference in the relationship between NDVI and rainfall can be caused by dominating soil and vegetation types and their individual rain use efficiencies.

This study was designed to test multiple hypotheses related to the past 33 years of vegetation greenness and climate sensitivity trends in Asia. We expected contrasting results for vegetation greenness and climate. The study results clearly show that the annual NDVI has a

significant positive relationship with the annual temperature and a significant negative relationship with the annual rainfall in humid and sub-humid climate areas of India, Thailand, and Southeast China. The NDVI shows a normal trend over time, which might indicate the improvement in the biomass productivity in last year due to increased water, vegetation and soil vegetation conservation efforts based on the increase of environmental conservation activities and cropland areas in this region during the study years.

The temperature and rainfall are expected to increase and decrease, respectively, during the dry season due to climate change, which would affect the majority of the vegetation cover. Our assessment supports a contradictory conclusion, which is in line with the findings by Chen et al. (2016) who reported a rapid increase of the annual NDVI in southern and southeastern China and India. Many researchers reported that higher temperatures in the temperate dry land might lead to earlier snowmelt (Pederson et al., 2011), an earlier onset of the growing season, and thus to higher productivity if the soil moisture conditions are favourable in spring (Yu et al., 2003).

In contrast to temperature, the predicted changes of the total annual rainfall are spatially heterogeneous, with potential decreases or increases at various locations; the uncertainty of rainfall forecasts is high compared with that of temperature forecasts (Maslin and Austin, 2012). However, there is a consensus that inter- and interannual rainfall variability will increase due to more frequent and extreme droughts, potentially leading to a loss in the vegetation biomass (Ruppert et al., 2015), and more heavy rain events (Fischer and Knutti, 2014). The conversion of the predicted rainfall variability increase into plant water availability is not straightforward due to factors such as rainfall intensity

(Knapp et al., 2008) and landscape and soil properties (Duniway et al., 2010; Gremer et al., 2015; Tietjen, 2016). For instance, no correlations were observed between vegetation and potential evapotranspiration in India, which is probably due to low evapotranspiration values.

One interesting finding was obtained for the area with minimum annual rainfall composed primarily of deserts that stretch from the Gobi Desert in Mongolia and China west–southwest through Pakistan and Iran. The summer season vegetation greenness in this area increased, which might indicate that desert plants have better adaptation capabilities than other plants. However, the temperature, rainfall, and evapotranspiration showed a normal trend in the Gobi Desert of southern Mongolia and China and climate change were insignificant. It is possible that such a process continuing for a long time would lead to greening. Climate change effects were apparent in other desert areas of Pakistan, Iran, Afghanistan, Turkmenistan, and Uzbekistan. Vegetation and rainfall were not correlated in these areas; rainfall was not a main limiting factor for vegetation growth and was sufficient for the types of vegetation in these arid and semiarid zones. This is in agreement with recent reports about the coincidence of low annual rainfall with extremely high evapotranspiration rates due to high summer temperatures, which leads to the rapid depletion of water reserves (Ceballos et al., 2004). To cope with the rapid moisture loss, a plant might make use of avoidance or tolerance mechanisms. In general, particular plant growth forms might have a selective advantage in desert environments by facilitating tradeoffs between the maximal net carbon gain and tolerance to environmental stress. For example, long-lived perennial shrubs and trees have relatively low net carbon gains and are buffered against environmental stress, whereas annuals possess high net carbon gain rates but restrict their active growth to relatively short periods when the soil moisture is high (Gibson, 1996). Desert plants have a good ability to withstand drying. The most extreme examples with respect to drought tolerance are resurrection plants. Resurrection plants are mainly poikilohydrous, which means that their water capacity adapts to the relative humidity in the environment. They are available to stand in a dehydrated state until the water becomes available, allowing them to rehydrate and retrieve full physiological activities. Resurrection plants can revive from an air-dried state as low as 0% (v/v) relative humidity (Gaff, 1987). And, we hypothesize the above our result which might be related to ground water depth consistent with previous studies (Zhu et al., 2015; Shang et al., 2016). In the previous study, found that about correlation between groundwater depth and gross primary productivity by vegetation type, climate characteristics and surface (Kolrala, S. et al., 2017).

Global warming is associated with hotter temperatures; however, it can also cause the opposite in local areas. Small areas of Thailand, Myanmar, and China showed decreasing annual and summer season temperatures; however, in northeast China, north Mongolia, and northeast Kazakhstan, the winter season temperatures decreased. Results of previous studies (Guang and Ming, 2013) suggested that energy consumption could be a missing force for additional winter warming trends of the observations. Strong warming (up to 1 °C) occurred in the Russian part of northern Asia. Eastern China also experienced warming of up to 0.5 °C. Guo (1994) pointed out that the East Asian winter mean surface air temperature is directly affected by the East Asian winter monsoon. Yan et al. (2002) reported that during the last 20th century in the China, gradual reduction of the number of the cold days and since 1961 an increase in the number of warm days.

The annual rainfall in Kazakhstan and a small area of southern and Southeast Asia increased. Liu et al. (2005) reported that the in China increased frequency of aggressive rainfall events affected 95% of the total rainfall increase between 1960 and 2000. In the during that time period, the total rainfall was increased 2%. Other researcher found that approximately two-thirds of all of the observed time series (1910–2000) in India demonstrated increasing indices of rainfall extremes and that there are coherent regions with increases or decreases (Roy and Balling, 2004). Zhaneldyk et al. (2006) suggested a weak increase (4%)

for the nationwide annual rainfall in Kazakhstan compared with that of the previous 30-year period (not published).

#### 4. Conclusion

Our study provides an analyses seasonal trends in NDVI and climate variables for finding correlations between vegetation greenness and climate variables. Our results indicate that temperature is the main climatic variable affecting the vegetation greenness in Asia because of its direct impact on the evapotranspiration. However, the climate impact on the vegetation growth is negligible in some areas of India, Thailand, and Southeast China. It is important to note that Bhutan, Nepal, northern India, Bangladesh, and northern Myanmar experienced an increasing temperature with decreasing rainfall, while the vegetation greenness decreased in Central Asia, northeastern and western China, and southern Mongolia. The vegetation greenness continuously increased in some areas of western India, eastern India, and southern and eastern China.

Our results indicated the strongest positive correlations between temperature and vegetation, rainfall and vegetation in Northeast China, Central China, northern Mongolia, northern Kazakhstan, North and South Korea, and northern Japan. The vegetation and potential evapotranspiration were weakly correlated in the northern part of Kazakhstan, the northern part of Mongolia, and northeastern China, which is probably due to short summer seasons. Regression analysis suggested that the vegetation greenness is related to two main climate factors (temperature, rainfall) in northern Mongolia, Northeast China, Central China, and North Korea.

We identified correlations between the vegetation greenness and climate variables by analyzing the seasonal trends of NDVI from remote sensed data and climate variables in this paper. But NDVI or greenness of the vegetation can be affected by many other environmental factors such as soil type, soil moisture, shallow groundwater level etc., especially in semiarid and arid regions. So, our findings deduced only through the relationship between the NDVI and climate variables should be improved with more detail analysis considering the environmental factors from different data sources in the future research.

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